

## INFLUENCE OF MACHINING PARAMETERS ON ELECTRIC DISCHARGE MACHINING OF WPS TOOL STEELS – AN EXPERIMENTAL INVESTIGATION

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### ABSTRACT

Electric Discharge Machining is capable of machining geometrically complex or hard material components, super alloys, ceramics, carbides, heat resistant steels etc. being widely used in die and mold making industries, aerospace, aeronautics and nuclear industries. The objective of this paper is to study the influence of operating parameters like discharge current, gap voltage, pulse-on time and pulse-off time for responses such as Material Removal Rate (MRR) and Surface Roughness (Ra) on the EDM of WPS DIN 1.2379/AISI D2 tool steel using the copper and graphite electrode material. The effectiveness of EDM process with WPS DIN 1.2379/AISI D2 is evaluated in terms of the Material removal rate and Surface roughness produced. Design of experiment is conducted with L9 orthogonal array and Multi- objective optimization is carried out with the help of Response surface methodology to optimize both the responses at the same time and it was found that the discharge current is the most influential parameter affecting the Material Removal Rate and Surface roughness.

**KEYWORDS:** Electrical Discharge Machining, Material Removal Rate, Surface Roughness, Response Surface Methodology, Design of Experiments

### INTRODUCTION

Electric Discharge Machining (EDM) is a controlled material removal technique where by high frequency electric sparks are used to erode the work piece which takes a shape corresponding to that of the tool electrode. The cutting tool (electrode) is made of electrically conductive material, usually copper or graphite. The electrode made to the shape of cavity required, and the workpieces required are both submerged in a dielectric fluid which is a nonconductor of electricity. A servomechanism maintains a gap of about 0.01m to 0.02m between the electrode and the work, preventing them from coming into contact with each other. A direct current of low voltage and high amperage is delivered to the electrode at a frequency of several KHz producing sparks of similar frequency between the electrode and the work piece through the dielectric fluid.

Intense heat is created in the localized area of spark impact, the metal melts or even vaporizes and gets expelled from the surface of workpiece. The dielectric fluid, which is constantly being circulated, carries away the eroded particles of metal during the off cycle of the pulse and also assists in dissipating the heat caused by the spark.

### LITERATURE SURVEY

A significant amount of work has been focused on ways of yielding optimal EDM performance measures of high metal removal rate (MRR), low tool wear rate (TWR) and satisfactory surface roughness (SR). J.S. Soni and G. Chakraverti [1] have explained the migration of material elements between the electrode and workpiece. The work piece used for this investigation is high carbon chromium die steel (T 215 Cr 12). They also studied the scanning electron

microscope (SEM) investigation on changes in the chemical composition of resolidified layers of the tool and the work piece as well as debris. The changes in chemical composition often remain confined to within resolidified layer which was supported by others [2] -[3]. O.A. Abu Zeid investigated the role of voltage, pulse-off-time in the electro discharge machined AISI T1 high speed steel [4].

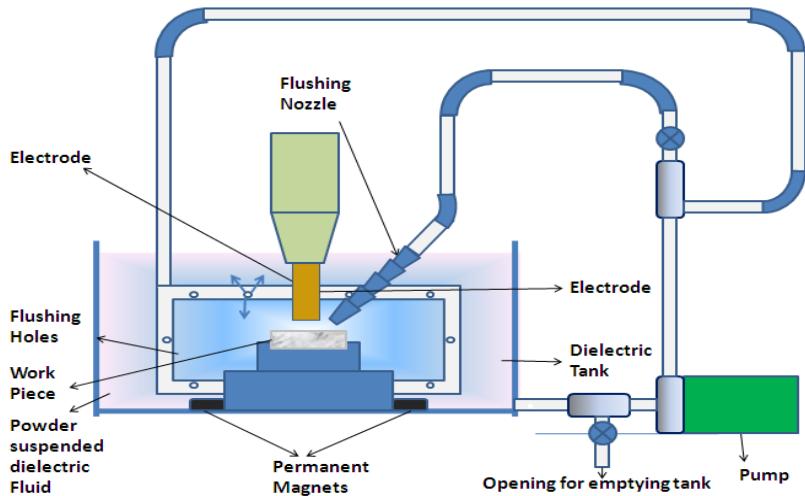
He found that the MRR is not very sensitive to off-time changes at a low pulse-on-time corresponding to finish machining. Volumetric electrode wear has been found to be less with shorter off-times when finish machining but is independently the off-time and direction of flushing. L.C. Lee, and L.C. Lim investigated the surface transformation and damage in AISI O1, A2, D2, and D6 steels after EDM [5]. According to them the electrical discharge machined surface of all the tool steels generally consists of three distinct layers the out most / white layer, an immediate layer and the unaffected parent layer. Pandey and Jilani [6] presented a thermal model of plasma channel growth and thermally damaged surface layer. They also drew the same conclusion that the EDMed surface has three distinct zones as that of Lee and Lim. Lim et al. [7] provides a review on the metallurgy of EDMed surface, which is dependent on the solidification behavior of the molten metal after the discharge cessation and subsequent phase transformation. The thickness of the recast layer formed on the workpiece surface and the level of thermal damage suffered by the electrode can be determined by analyzing the growth of the plasma channel during sparring. EDMed surface has a relatively high micro hardness, which can be explained by the emigration of carbon from the oil dielectrics to the workpiece surface forming iron carbide in the white layer [8]. The concentration of carbides, both as the surface layer of the work piece and as fine debris, is dependent on the frequency and polarity of the applied current together with other processing parameters such as pulse shape, gap spacing, and dielectric temperature [9]. Thompson argued that the pulse duration and type of electrode material under a paraffin dielectric has an effect on the amount of carbon contamination [10].

C.H. Kahn and K.P.Rajukar [11] found that the discharge time for the application of fine cutting conditions to improve the surface characteristics should not be estimated on the basis of surface geometry improvement only because the removal of the white layer and heat affected zone including cracks requires considerable discharge time. The EDM of advanced ceramics has been widely accepted by the metal cutting industry owing to competitive machining costs and features. Koing, and Dauw [12] classified different grades of engineering ceramics as nonconductor, natural conductor and conductor. Sanchez et al. [13] provided a literature survey on the EDM of advanced ceramics, which has been commonly machined by ultrasonic machining (USM) and laser beam machining (LBM), and proved the feasibility of machining Boron Carbide (B4C) and Silicon infiltrated Silicon Carbide (SiSiC) using EDM and wire electric discharge machining (WEDM). A combination of USM and EDM was also experimented to enhance the dielectric circulation in the spark gap, while machining ceramics with significant improvement in the performance measures and a reduction in the thickness of the white layer [14]. A lot of literature is found in the case of die and tool steels, ceramics and metal matrix composites. But the available literature on super alloys such as Ti-6Al-4V, and maraging steels (M250) is scanty. The present work is concentrated in high carbon high chromium WPS 1.2379 tool steel which is extensively used in aerospace, automobile, shipbuilding, valves, pump shafts, heat exchangers and molds and dies etc.

## EXPERIMENTAL DETAILS

The material used in these experiments was WPS DIN 1.2379 tool steel material having size 10x40x40 mm with square shaped copper and graphite tool with 10x10x30 mm dimensions were used. Separate workpiece is used for each experiment using both copper and graphite as an electrode tools and commercial grade EDM oil (specific gravity= 0.763, freezing point=94°C) is used as a dielectric fluid. A square shaped copper and graphite electrodes with EDM Oil is used to flush away the eroded materials from the sparking zone. In this machining time and duty cycle is kept constant is 30 mins

and 0.75. For four factors are tackled with a total number of 18 experiments for copper electrode were performed. Electrical discharge machine (EDM) was used to machine on the workpiece for conducting the experiments.



**Figure 1: Set up of Electric Discharge Machining**

**Table 1: Composition of WPS Tool Steel Material**

| Elements | Weight Limits % | Actual Weight % |
|----------|-----------------|-----------------|
| C        | 1.5-1.8         | 1.5             |
| Ch       | 10-12           | 12              |
| V        | 1.00-2.15       | 1.00            |
| Mo       | 1.00-2.00       | 1.00            |

**Table 2: Mechanical Properties of WPS Tool Steel**

| Properties           |  |
|----------------------|--|
| Density              | $7.70 \times 10^3 \text{ kg/m}^3$                        |
| Thermal conductivity | $40.9-55.2 \times 10^{-3} \text{ cal/cms}^\circ\text{C}$ |
| Elastic Modulus      | 173-193Gpa   |



**Figure 2: Copper and Graphite Electrodes Samples**

**Table 3: 7 Chemical Composition of Copper and Graphite Electrodes**

| Cu%  | Zn%   | Al%  | Bi%    | Pb %   |
|------|-------|------|--------|--------|
| 99.8 | 0.057 | 0.15 | 0.0011 | 0.0008 |

| C%        | S%   | Fe%   |
|-----------|------|-------|
| Above 75% | 0.5% | 2.00% |



**Figure 3: WPS Tool Steel Workpiece Samples before Machining and after Machining**

#### Evaluation of MRR

The material removal rate is expressed as the ratio to the difference of weight of the workpiece before machining and after machining measured by a precision weight balance of the machining time.

$$MRR = \frac{W_b - W_a}{t}$$

Whereas,  $W_b$  = weight of workpiece before machining;  $W_a$  = weight of workpiece after machining;  $t$  = machining time.

#### Evaluation of Surface Finish

Surface finish is expressed as  $R_a$  value in micro meter and is measured with the help of contact type surface roughness tester.

### RESULTS AND DISCUSSIONS

#### For Copper Electrode

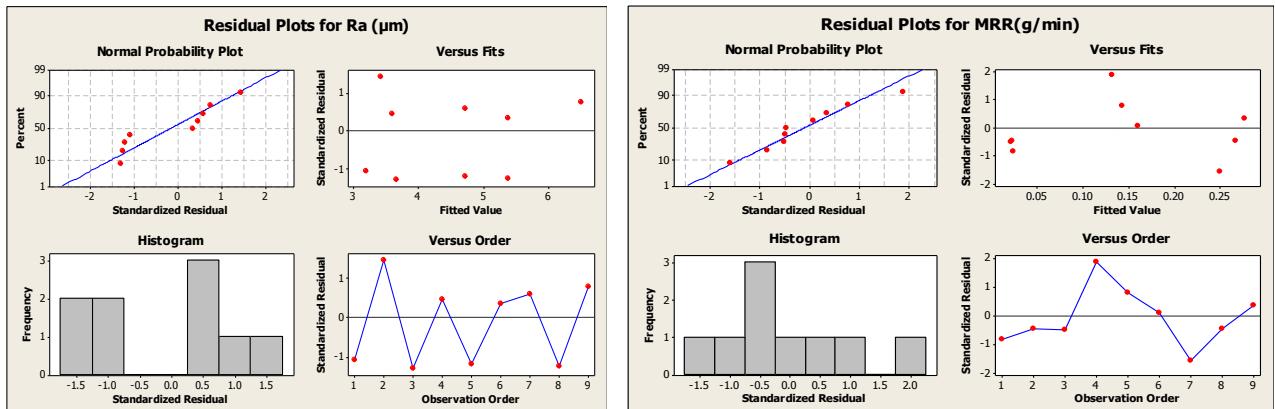
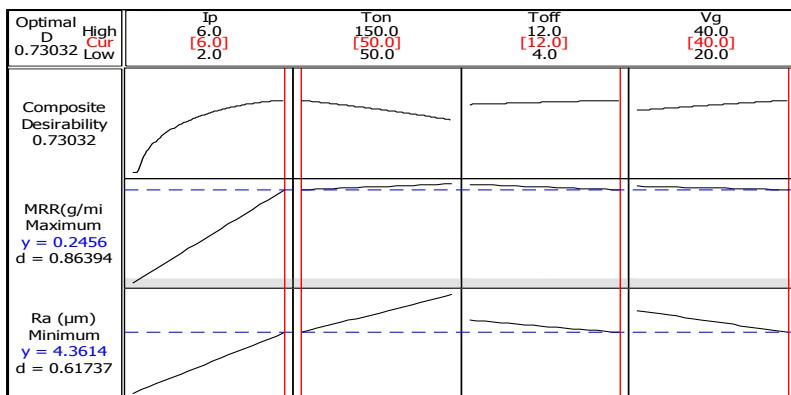
Comparing the p-value to a commonly used  $\alpha$ -level=0.05, it is found that if the p-value is less than or equal to  $\alpha$ , it can be concluded that the effect is significant. ANOVA for MRR of Copper electrode for the facts as shown in table 1 which clearly indicates that the discharge current has the greatest influence on the Material Removal Rate (MRR) and Surface roughness, followed by pulse on time( $T_{on}$ ), pulse off time ( $T_{off}$ ) and gap voltage ( $V_g$ ). The p- values for  $I_p$ ,  $T_{on}$ ,  $T_{off}$  and  $V_g$  are 0.0001, 0.387, 0.429 & 0.646 and 0.0001, 0.08, 0.170, 0.166 for surface roughness respectively, depicted in Table1.

**Table 4: Analysis of Variance for MRR for Copper Electrode**

| Source       | DF       | Seq SS          | Adj SS   | Adj MS   | F      | P      |
|--------------|----------|-----------------|----------|----------|--------|--------|
| Regression   | 4        | 0.089547        | 0.089547 | 0.022387 | 59.35  | 0.001  |
| Linear       | 4        | 0.089547        | 0.089547 | 0.022387 | 59.35  | 0.001  |
| $I_p$        | 1        | 0.088768        | 0.080084 | 0.080084 | 212.33 | 0.0001 |
| $T_{on}$     | 1        | 0.000445        | 0.000355 | 0.000355 | 0.94   | 0.387  |
| $T_{off}$    | 1        | 0.000241        | 0.000292 | 0.000292 | 0.77   | 0.429  |
| $V_g$        | 1        | 0.000093        | 0.000093 | 0.000093 | 0.25   | 0.646  |
| Error        | 4        | 0.001509        | 0.001509 | 0.000377 |        |        |
| <b>Total</b> | <b>8</b> | <b>0.091055</b> |          |          |        |        |

**Table 5: Analysis of Variance for SR for Copper Electrode**

| Source       | DF       | Seq SS         | Adj SS  | Adj MS  | F      | P      |
|--------------|----------|----------------|---------|---------|--------|--------|
| Regression   | 4        | 12.8550        | 12.8550 | 3.21374 | 44.77  | 0.001  |
| Linear       | 4        | 12.8550        | 12.8550 | 3.21374 | 44.77  | 0.001  |
| $I_p$        | 1        | 10.5073        | 8.8798  | 8087981 | 123.71 | 0.0001 |
| $T_{on}$     | 1        | 2.0068         | 1.6956  | 1.69562 | 23.62  | 0.008  |
| $T_{off}$    | 1        | 0.1350         | 0.2009  | 0.20090 | 2.80   | 0.170  |
| $V_g$        | 1        | 0.2059         | 0.2059  | 0.20581 | 2.87   | 0.166  |
| Error        | 4        | 0.2871         | 0.2871  | 0.07178 |        |        |
| <b>Total</b> | <b>8</b> | <b>13.1421</b> |         |         |        |        |

**Plot 1: Residual Plots for MRR and SR for Copper Electrode****Plot 2: Optimization Plot for Copper Electrode**

The optimization plot shows how the factors affect the predicted responses and allows you to modify the factors settings interactively indicates the composite desirability. It is observed that discharge current is the most influential parameter affecting both Material removal rate and Surface Roughness mainly this is due to discharge energy released during this time and expanding the discharge channel and hence the impulsive force increase and results in the formation of deeper and larger discharge craters, which in turns increases surface roughness. It can be observed that increase in pulse on time results in an increase in the surface roughness. This is due to the expansion of plasma channel with increase in pulse on time which results in wider contact zone of discharging, thereby reducing both energy density and the impulsive force.

#### For Graphite Electrode

**Table 6: Analysis of Variance for MRR of Graphite Electrode**

| Source     | DF | Seq SS   | Adj SS   | Adj MS   | F     | P     |
|------------|----|----------|----------|----------|-------|-------|
| Regression | 4  | 0.089547 | 0.089547 | 0.022387 | 59.35 | 0.001 |
| Linear     | 4  | 0.089547 | 0.089547 | 0.022387 | 59.35 | 0.001 |

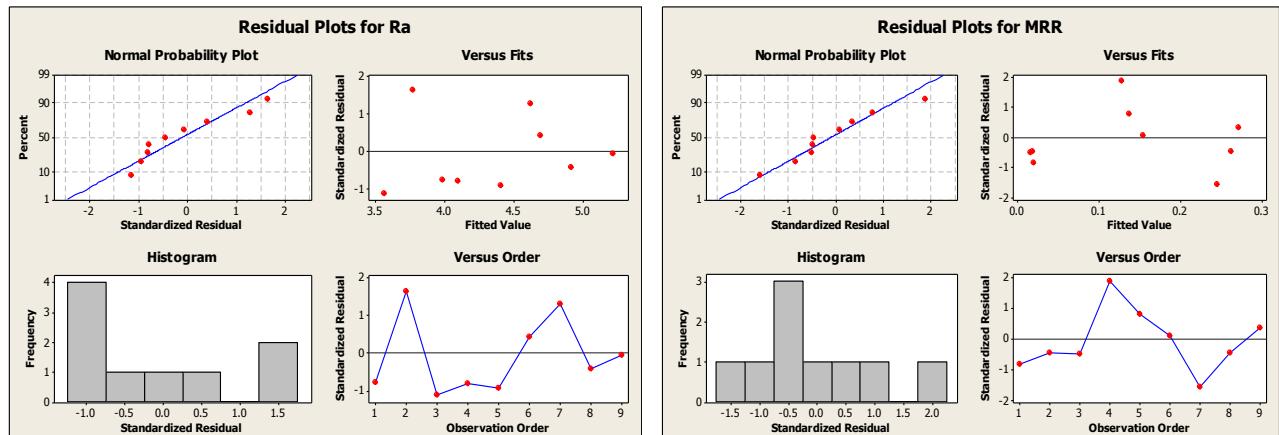
Table 6: Contd.,

|              |          |          |          |          |        |        |
|--------------|----------|----------|----------|----------|--------|--------|
| $I_p$        | 1        | 0.080084 | 0.080084 | 0.080084 | 212.33 | 0.0001 |
| $T_{on}$     | 1        | 0.000355 | 0.000355 | 0.000355 | 0.94   | 0.387  |
| $T_{off}$    | 1        | 0.000292 | 0.000292 | 0.000292 | 0.77   | 0.429  |
| $V_g$        | 1        | 0.000093 | 0.000093 | 0.000093 | 0.25   | 0.646  |
| Error        | 4        | 0.001509 | 0.001509 | 0.000377 |        |        |
| <b>Total</b> | <b>8</b> |          |          |          |        |        |

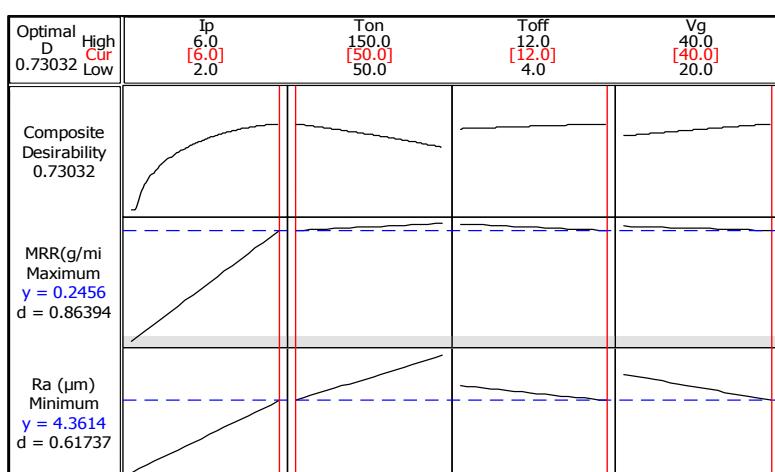
Table 7: Analysis of Variance for SR of Graphite Electrode

| Source       | DF       | Seq SS         | Adj SS  | Adj MS  | F     | P     |
|--------------|----------|----------------|---------|---------|-------|-------|
| Regression   | 4        | 2.65968        | 2.65968 | 0.66492 | 9.11  | 0.027 |
| Linear       | 4        | 2.65968        | 2.65968 | 0.66492 | 9.11  | 0.027 |
| $I_p$        | 1        | 2.45760        | 1.92963 | 1.92963 | 26.45 | 0.007 |
| $T_{on}$     | 1        | 0.00735        | 0.00004 | 0.00004 | 0.00  | 0.983 |
| $T_{off}$    | 1        | 0.03227        | 0.06460 | 0.06460 | 0.89  | 0.400 |
| $V_g$        | 1        | 0.16246        | 0.16246 | 0.16246 | 2.23  | 0.210 |
| Error        | 4        | 0.29181        | 0.29181 | 0.07295 |       |       |
| <b>Total</b> | <b>8</b> | <b>2.95149</b> |         |         |       |       |

Comparing the p-value to a commonly used  $\alpha$ - level = 0.05, it is found that if the p- value is less than or equal to  $\alpha$ , it can be concluded that the effect is significant. ANOVA for surface roughness for Graphite electrode is shown in the Table 3 and 4 which clearly indicates that the discharge current has the greatest influence on material removal rate and surface roughness followed by  $V_g$ ,  $T_{off}$  and  $T_{on}$  are 0.0001, 0.387, 0.429, 0.646 for MRR and 0.007, 0.210, 0.400 and 0.983 for SR respectively



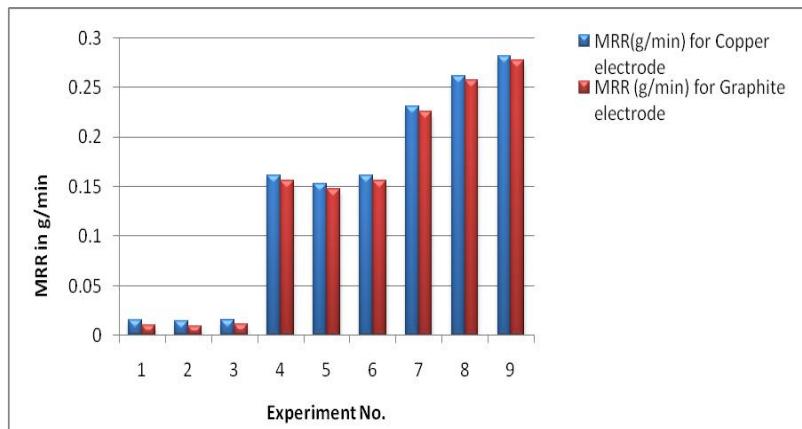
Plot 3: Residual Plots for MRR and SR for Graphite Electrode



Plot 4: Optimization Plot for Graphite Electrode

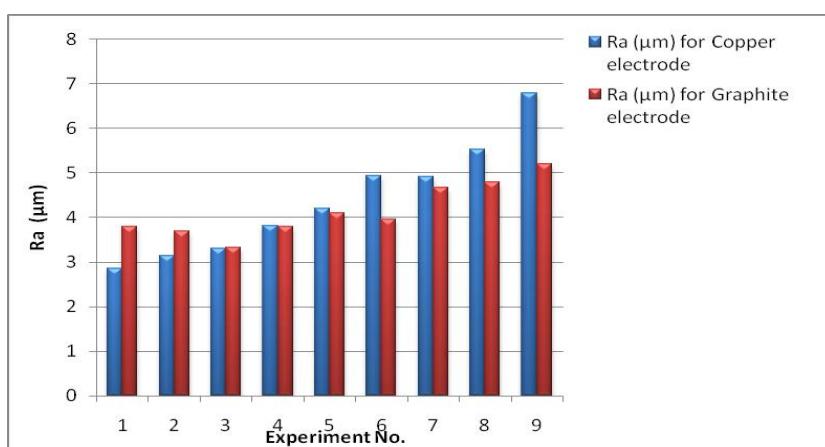
It is observed that discharge current is the most influential parameter affecting both Material removal rate and Surface Roughness due to discharge energy released during this time and expanding the discharge channel and hence the impulsive force increases and results in the formation of deeper and larger discharge craters. It can be observed that increase in pulse on time results in an increase in the surface roughness. This is due to the expansion of plasma channel with increase in pulse on time which results in wider contact zone of discharging, thereby reducing both energy density and the impulsive force.

## CONCLUSIONS



**Graph 1: Comparison of MRR for Copper and Graphite Electrode**

It can be seen that the material removal rate for copper electrode is much better than that of graphite electrode for the same parameters in each experiment. Hence Copper electrode is much more suitable than that of Graphite electrode as it removes maximum material rate. A comparison of process performance of Graphite electrode with a Copper electrode in EDM as a tool material proven less beneficial because stable machining conditions have established at low discharge energy (when discharge current is in the range of 2 to 6 amperes) resulting in low spark frequency which is beneficial for copper electrode for EDM operation.



**Graph 2: Comparison of Surface Roughness for Copper and Graphite Electrodes**

It can be seen that the surface finish for Copper electrode is better for the low discharge current i.e. 2 amperes, as the current go on increasing the surface roughness goes on increasing, whereas for graphite electrode the surface roughness is more for the lower value of current i.e. from 2-4 amperes, whereas the surface roughness decreases for the higher value of the current. The comparison has been proven less beneficial for graphite electrode at lower values of discharge current

but proves beneficial for the higher discharge current values, when the discharge current is in the range from 4-6 amperes, thus high spark frequency which improves the surface finish for Graphite electrode.

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